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IMPROVED PROJECTILE DIVERTER

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Background of the Invention

This application is a continuation-in-part of pending U.S. Application No. 09/502,119, filed on February 10, 2000, which entire disclosure is incorporated herein by reference. The present invention relates to controlling the flight path of rockets, missiles, and other flying projectiles. In particular, the invention relates to a small fast diverter for use with a projectile for steering the projectile in flight.

In general, a diverter generates lateral reaction force to steer a rocket, missile, and other projectile in flight. The amount of impulse generated by the diverter will determine how much the flight path is diverted. Impulse is the product of the average reaction force over the time exerted.

Recent applications for diverters include steering 2.75-inch diameter rockets, artillery, and gun projectiles, e.g., 30 mm projectiles. In such applications, we need small diverters that can generate relative high impulse (e.g., 1 to 5 N-sec) in short time periods. Because rockets, missiles, and projectiles often spin at high rates, the impulses must be made in a short time period, e.g., on the order of 1 ms. If, for example, a projectile is spinning at 3600 RPM, it is spinning at 60 revolutions per second or 21.6 degrees per millisecond. If the diverter provides a reaction force for 10 ms, this will provide force over 216 degrees. Providing the force over this time period is not efficient. Instead, we would like to provide the force for 1-ms or less. If the diverter can provide the force over this shorter period, the guidance system can make multiple steering corrections when

needed as a projectile flies through space by igniting the multiple diverters arranged around it.

One might consider using small rocket motors for diverters having small volume, but this has proven ineffective when a relatively high impulse is required over a short time. It is too difficult for a rocket motor with loose loaded propellant to burn all of its propellant in a short time without ejecting a large percentage of the propellant unburned. Further, the relatively low packing density of propellant results in the rocket motor ejecting a considerable volume of propellant. Additionally, the rocket propellant container cannot be manufactured that small. Providing the propellant in a higher density form, e.g., cast propellant grain, might appear helpful, but a compact single grain is unlikely to have a thin enough web to operate in the required time period due to propellant burn rate limitations. Where low cost is required, such as less than $5.00 per diverter, without large capital investment, it is difficult to envision good results with rocket motors. Small rocket motors can provide impulses of 1-5 N-sec, but for longer time periods on the order of 10 milliseconds. Additionally, rocket motors are not volume efficient for another reason. To fully use the energy in a rocket propellant, a converging/diverging nozzle with significant mass and volume is needed to fully expand and accelerate the propellant gas.

Another approach might be to use conventional bridgewire pyrotechnic devices for small diverters, but there are unsolved problems. One problem is how to ignite them quickly and reliably. Conventional semiconductor bridge technology provides very fast hot ignition, but it is also only low energy ignition lasting for microseconds. The energy output is dependent on energy input; when only low input energy is available, only small output energy can be produced, which may not be sufficient to provide reliable ignition. Further, conventional pyrotechnic devices and semiconductor bridges require tight coupling between the ignition element and the pyrotechnic material. Up to now it has been critical for reliable ignition with semiconductor bridges that the ordnance or pyrotechnic material to be ignited be in close contact with the semiconductor bridge during ignition. This means lower ignition energy can be used, but it requires intimate contact

between the bridge and prime, adding to manufacturing costs. The applications mentioned earlier can subject diverters to very high accelerations and shocks, e.g., on the order of 100,000 g's. During such events the prime may separate from the ignition element and reduce the reliability of the diverter. Bridgewires require high firing energies or very small and unsafe bridgewires for fast response. Thus, attempts to produce small low cost diverters generating relatively high impulse over brief periods of time have not been successful.

Summary of th Invention

The present invention provides a small, fast, low cost diverter for steering a rocket, missile, or other projectile.

One embodiment of the diverter uses a reactive semiconductor bridge for the ignition source and ejects an end cap from a diverter body to generate a fast relatively high impulse. A header assembly extends into the diverter body and supports the reactive semiconductor bridge and provides electrical contact to a fireset. When desired, the reactive semiconductor bridge provides fast ignition of the prime and allows for a gap between the semiconductor bridge and the prime. The ignited prime in turn ignites the propellant. The burning propellant produces gases, which are confined in the diverter until the pressure builds to the point when the end cap of the diverter is ejected. Requiring the propellant to generate high pressures to eject a solid mass such as an end cap is a much more efficient method of retrieving the energy from the propellant than ejecting hot gases from a rocket motor.

One advantage of the present invention is a relatively low cost, high impulse compact, and fast functioning diverter results compared to what can be provided with a small rocket motor. The use of the reactive semiconductor bridge allows very fast firings since ignition occurs in microseconds. The reactive semiconductor bridge allows reliable operation at low input energies since the reactive semiconductor bridge provides a large energy output to ignite the prime. The reactive semiconductor bridge can ignite prime across a gap and this provides a safety margin in case the shock or acceleration of projectile launch would cause the prime to become separated from the bridge. Reliable diverters can be therefore built at relatively low cost using this technology.

Thus, in one embodiment, the invention relates to a small fast diverter for use with a projectile for steering the projectile in flight by ejecting an end cap of the diverter in response to a signal from a guidance system. In another embodiment, the invention relates to a diverter and other impulse type of cartridges capable of high impulse, such as less than 1 ms, without throwing a mass such as the end

cap, but instead using the ejection of the hot high-pressure velocity gases out of the diverter body.

Brief D scripti n of th Drawings

Figure 1 illustrates a cross-sectional view of a rocket with a single diverter installed on the right hand side.

Figure 2 illustrates a perspective view of the rocket with three bands of diverters. Each band may include eight diverters like those shown in Figures 1 and 3B. The view includes a partial cross-section through the first of the three bands of diverters.

Figure 3A is an end view of the diverter shown in Figure 1.

Figure 3B is a detailed cross-section of the diverter shown in Figure 1.

Figure 4A is an electrical lead end view of the header assembly shown in Figure 4B.

Figure 4B is a cross-section of the header assembly shown in Figure 3B.

Figure 4C is a semiconductor bridge end view of the header assembly shown in Figure 4B.

Figure 5A is a detailed cross-section of the semiconductor bridge shown in Figure 3B.

Figure 5B is a view of the semiconductor bridge mounted on the header assembly shown in Figures 3B and 4C.

Figure 6 is a detailed cross-section of an alternative embodiment of the diverter shown in Figure 3B.

D tail d Description of the Preferred Embodiments

Figure 1 shows a cross-sectional view of a rocket 10 with a single diverter 12 on the right side. In this embodiment, the rocket 10 is a 2.75-inch diameter rocket. It should be apparent from the specification, however, that the diverter would be useful on many types of projectiles. As shown in Figure 1, the core of rocket 10 has eight barrels 1, 2, 3, 4, 5, 6, 7, and 8 for installing eight diverters, just like diverter 12, in a band about the rocket 10. The rocket 10 includes a free passage 9 to allow connection of each of the diverters 12 to the fireset (not shown).

The diverters can be arranged in several bands about the rocket 10 as shown in Figure 2. Figure 2 illustrates a perspective view of the rocket 10 with three bands of diverters 12. Each band includes eight diverters, but other amounts are possible besides those shown in Figures 1-2. Figure 2 shows a partial cross-section through the first of three bands of diverters.

As shown in Figures 1-2, the diverters have axes perpendicular to the axis of rocket 10, such that the ejection of an end cap 16 from a diverter body 22 will produce a lateral reaction force. It may be desirable to have from 1 to 64 diverters on the rocket 10. It is preferred that the diverter axes be perpendicular to the rocket axis and arranged at equal angles apart to simplify guidance system calculations.

Figure 3B shows additional details of the diverter 12 shown in Figure 1. As shown in Figure 3B, the diverter 12 includes an end cap 16, made of strong steel, preferably of 17-4 PH CRES, condition H-1025, with a clean passivated finish. The end cap 16 is attached to the diverter body 22, and made of the same material and finish as the end cap 16. A conventional adhesive bonding material 26, such as a cyano acrylate adhesive, a suitable conventional structural epoxy, or a conventional urethane adhesive, is applied on the contacting surfaces between the end cap 16 and the diverter body 22 to bond the end cap 16 to the diverter body 22 until the time that the end cap 16 is ejected. One of ordinary skill would also understand that the end cap 16 and the diverter body 22 could be also attached by other techniques such as crimping. The end cap 16 is filled with

a loosely loaded propellant 14, preferably 50 wt. % Bullseye (pistol powder) and 50 wt. % HMX (an explosive ordnance material), shotgun powder or the like. In an optional feature, the invention provides a conventional adhesive backed paper closure, which acts as a thermal closure 24, to seal and hold the propellant 14 in place for handling during assembly of the diverter 12.

The diverter body 22 contains the prime 18, preferably zirconium potassium perchlorate, or a similar ordnance material. The diverter body 22 has an aperture for housing the header assembly 20. The header assembly 20 includes a glass substrate 44 from which two electrical leads 30 and 32 protrude to provide electrical contact from a fireset (not shown) to a reactive semiconductor bridge 40 mounted on the other end of the header assembly 20. Electrical leads 30 and 32 are made of stainless steel or KOVAR. Conventional shrink tubing 34 and 36 insulates the electrical leads 30 and 32 from contacting and shorting to the diverter body 22. Conventional potting material 28 retains the shrink tubing 34 and 36 and fills the gap between the shrink tubing 34 and 36 and the diverter body 22. A conventional shunt 38 provides an electrical short when attached to the electrical leads 30 and 32 for safe handling of the diverter 12, and which shunt is removed when the diverter 12 is attached to the fireset. Figure 3A is an electrical lead end view of the diverter 12 shown in Figure 3B.

Figure 4A shows the end of header assembly 20 from which electrical leads 30 and 32 protrude. Figure 4B shows a cross-section through the header assembly 20, including the glass substrate 44, the stainless steel sleeve or eyelet 42, and the electrical leads 30 and 32, and also through the semiconductor bridge 40. Figure 4B includes detail A shown as Figure 5A, and a view B-B shown as Figure 5B. Figure 4C shows the end of the header assembly 20 on which the semiconductor bridge 40 is mounted.

Figure 5A is a close up and a cross-section of the semiconductor bridge 40 mounted on the header assembly 20, labeled detail A in Figure 4B. Figure 5B is an end view. The reactive semiconductor bridge 40 is shown as mechanically attached on the header assembly 20 by a non-conductive epoxy 47 such as Able Bond 84-3. Electrical leads 30 and 32 provide an electrical contact point on the

header assembly 20. Electrically conductive epoxy 46 and 45 such as Able Bond 84-1 electrically connect each of the contact pads of the semiconductor bridge 40 to the electrical leads 30 and 32.

In operation, the reactive semiconductor bridge 40 provides fast ignition of the prime 18 even when there is a gap between the semiconductor bridge 40 and the prime 18. A suitable reactive semiconductor bridge 40 and the associated structures are described in detail in U.S. Patent Nos. 5,847,307 and 5,905,226, which patents are hereby incorporated by reference.

After the semiconductor bridge 40 is triggered based on electrical signals from the fireset, hot plasma forms, igniting the prime 18, which in turn ignites the propellant 14. Burning propellant 14 produces gases, which are confined in the diverter 12 until the pressure builds to the point where the end cap 16 is ejected. Ejecting the end cap 16 is more efficient than generating an impulse by rocket propellant. The ability of the reactive semiconductor bridge 40 to ignite the prime 18 across the gap provides a margin of safety in case the shock or acceleration of the launch causes the prime 18 to separate from the semiconductor bridge 40. Diverters 12 can be built at low cost using this technology.

In a preferred embodiment, the diverter body 22 has an undercut 48 such that the mouth of the diverter body 22 is smaller than the base as shown in Figure 3B to hold the prime 18 in place during high shock conditions and during ignition. When fired a semiconductor bridge 40 tends to throw off the prime 18 rather than ignite it unless the prime 18 is retained. The undercut 48 retains the prime 18 in place during firing. The reactive semiconductor bridge 40 allows a gap between the semiconductor bridge 40 and the prime 18. It should be noted that the reactive semiconductor bridge 40 ignites the prime 18 across a gap, but not necessarily if the prime 18 is allowed to dynamically shift away from the semiconductor bridge 40 during the firing process.

Methods of the present invention provide the following steps: a firing signal from the fireset is transmitted to the electrical leads 30 and 32 of the diverter 12 when the shunt 38 is removed. The voltage level of fire signal required depends upon

the type of the semiconductor bridge 40 mounted on the header assembly 20. The firing signal can be supplied by many methods including applying one of the following:

1) A constant current of 1 to 10 amps for less than 1 ms. The actual current will depend on the sensitivity and type of semiconductor bridge used.

2) A capacitive discharge of, e.g., approximately 25 volts from a 40-microfarad capacitor would be typical for driving a semiconductor bridge, but values down to 3 volts and capacitor values down to less than 1 microfarad are possible when highly sensitive semiconductor bridges are used. Higher voltages, voltages up and greater than 500 volts can be used with junction semiconductor bridges that have DC blocking.

3) A voltage signal whose value depends on the semiconductor bridge type, properties, and characteristics.

The firing signal causes the semiconductor bridge 40 to generate hot plasma (>2000 F) that ignites the prime 18. The prime 18 is designed to ignite promptly when driven by the semiconductor bridge 40 and generate in less than 100 microseconds hot particles and heat. The hot particles and heat from the ignited prime ignite the propellant 14. The propellant 14 is designed to rapidly burn resulting in a rapid pressure rise in the volume confined by the end cap 16 and the diverter body 22. Each diverter 12 is contained within a barrel as shown in Figures 1-2. The electrical lead end of the barrel is closed to match the taper at the back of the diverter 12. The taper is provided on the diverter 12 so the diverters can be placed close together. A slot, not shown, is cut in the side of the back of the barrel to allow the electrical wires to exit and make connection to the fireset. The opposite end of the barrel is open as shown in Figures 1-2. As the pressure builds inside the diverter 12 produced by the burning of the prime 18 and the propellant 14, the end cap 16 outer diameter swells and seals against the inner diameter of the barrel defined by the rocket 10. Also the pressure forces the diverter body 22 back against the taper sealing this potential exit path for hot gas. The header assembly 20 is mounted on the diverter body 22. As the

pressure within the diverter 12 continues to increase from the burning of prime 18 and propellant 14, the force on the end cap 16 reaches a point where the end cap 16 separates from the diverter body 22 and is accelerated down the barrel and ejected. Ejecting the end cap 16 results in a reaction force, that is, the diverting force. Additionally, diverting force is created by the reactive forces from the ejection of the hot gases from the burning of the prime 18 and the propellant 14 out of the barrel similar to the operation of a rocket.

Figure 6 illustrates an alternative embodiment of the diverter, which does not throw a solid mass. As in the previous embodiment, the diverter 50 includes a diverter body 52 having a glass substrate 54 joined to a set of pins or leads 56 and 58. This produces a glass-to-metal seal header assembly 60 where the leads 56 and 58 enter the header assembly 60. A suitable ignition element such as a semiconductor bridge 40 is electrically attached to the leads 56 and 58 that exit the glass substrate 54. Preferably, the leads 56 and 58 extend to the exit end of the diverter body 52, for example, near the solder connection 64. The semiconductor bridge 40 mounts on a mounting surface of an assembly, which seals off the exit end of the diverter body 52. One suitable mounting surface is a glass laminate printed circuit board (PCB) 62, which includes conductive paths to connect opposite ends of the semiconductor bridge 40 to the respective leads 56 and 58. A solder connection 64 connects the electrical lead 58 to one conductive path associated with the PCB 62. Solder connection 76 connects electrical lead 56 to the other conductive path leading to the other end of the semiconductor bridge 40. Any suitable connection method can replace the solder connections, for example, either crimping or conductive epoxy. Conductive epoxy may be preferred over solder connections 64 and 76, because the propellant 66 is typically loaded in the diverter body 52, the prime 18 is applied to the semiconductor bridge 40, and they may ignite from a hot solder connection or from mechanically pinching the prime 18 or the propellant 66.

In the embodiment shown in Figure 6, the insulating sleeves 68 and 60 cover the leads 56 and 58 to minimize the danger of an electrostatic discharge (ESD) igniting the prime 18 or shorting to the diverter body 52. Either lead 56 or lead 58

can be tied to diverter body 52 to minimize the risk of lead-to-lead ESD ignition from the diverter body 52. That tied lead can be closed with crimp or any other standard closing process. The sealing assembly of the embodiment shown in Figure 6 also includes a metal end closure 72 sealed with a crimp 74 and with epoxy adhesive (not shown).

In operation, the control system applies power to the leads 56 and 58 that ~~it~~ applies power to the conductive paths to the semiconductor bridge 40. The semiconductor bridge 40 ignites the prime 18, which ignites the propellant 66 at the interface between the prime 18 and the propellant 66. The propellant 66 starts to burn, exerting restraining force on the unburned propellant 66 until the propellant 66 is consumed.

A reactive semiconductor bridge 40 can provide fast ignition of the prime 18. The ignited prime 18 ignites propellant 66, namely, compacted energetic ordnance materials that burn rapidly, such as zirconium potassium perchlorate. The gases created by the burning or rapid deflagration of this energetic material serve to restrain the un-reacted propellant 66 until it is consumed.

Accordingly, the diverter 50 functions like an initiator, but the semiconductor bridge 40 is preferably at the exit end of the diverter body 52 so that the energetic column of the propellant 66 is ignited at the exit end rather than at the bottom. Another approach is to ignite the propellant 66 at the bottom of the diverter 50, but it is believed to expel the propellant 66 out of the diverter 50 before its completely burned. Thus, we prefer to ignite the propellant 66 at the exit end to keep unburned propellant 66 in place until it is completely consumed, resulting in more efficient use of the energy stored in the propellant 66.

A reactive semiconductor bridge 40 is also preferred, because it allows a gap between the semiconductor bridge 40 and the prime 18, which permits the semiconductor bridge 40 to fire even if the prime 18 moves away from the semiconductor bridge 40. As before, the reactive semiconductor bridge 40 will ignite the prime 18 across a gap, but not always when the prime 18 dynamically moves away during the firing process. With the semiconductor bridge 40 firing

a into the prime 18, the prime 18 is retained by the exit end of the diverter ~~16~~ 50 holding the propellant 66 in the diverter body 52.

The operation of the alternative embodiment is identical with that of the previous embodiment, except that as follows:

1) The hot particles and heat from the ignited prime 18 ignites the propellant 66 from the exit end of the diverter 50.

2) The propellant 66 is formulated and configured in such a manner as to burn very rapidly, preferably, e.g., less than one millisecond.

3) The reaction from the burning of the propellant 66 results in the diverting force rather than reaction from throwing the end cap 16. The diverting force is created by the ejection of the hot high-pressure high velocity gases from the burning of the prime 18 and the propellant 66 out of the diverter body 52 similar to the operation of a rocket.

There are other advantages to this alternative embodiment. First, it provides high impulse in a small package. Second, it does not throw a solid mass, which can cause fratricide to adjacent missiles and rockets and pose to risk to personnel on the flight path, e.g., friendly troops. The use of the reactive semiconductor bridge 40 allows very fast firings, since the ignition occurs in microseconds. It also allows reliable operation at low input energies, since the reactive semiconductor bridge 40 provides a large energy output to ignite the prime 18. The reactive semiconductor bridge 40 can ignite across a gap, providing a margin of safety against the shock or acceleration of a launch, which can cause the prime 18 to separate from the semiconductor bridge 40. The diverter 50 can be built at low cost using well known impulse cartridge technology. This will be cost effective compared to a rocket motor with a nozzle and use of a solid grain. Thus, the alternative embodiment provides an inverted ignition structure does not need to throw a solid mass, and achieves a relatively high impulse in very short time periods at low cost. The reactive semiconductor bridge provides for shock insensitivity, and the propellant and the prime can be different ratios to provide the desired impulse. Finally, a nozzle can be attached to the diverter 50 to

increase the impulse, and make the impulse cartridge function like a rocket motor.